Chapter Twenty-five

GPS Survey Control Network

25-1.0 GENERAL

The primary purpose for employing the global positioning system (GPS) is to establish better survey control in road design by improving angular control on long, narrow traverses. Employing GPS technology usually saves considerable time during the survey because the conventional traverse and the level circuits typically only need to be run in one direction.

The traditional use of the United States Coast & Geodetic Survey (USC&GS) for horizontal control frequently results in a repeatability error that is outside an acceptable tolerance. A GPS control survey can minimize such errors because it will facilitate a reference to state plane coordinates (SPC) which will allow any future control to be re-established within a tolerance of only a few centimeters. Establishing control by referencing SPC will become increasingly important once the Federal Base Network/Cooperative Base Network (FBN/CBN), formerly known as the High Accuracy Reference Network (HARN), has been completed and adjusted. If a section corner or centerline control monument is based on adjusted FBN/CBN SPC, then it can be readily and accurately re-established by use of any local monument that is also based on FBN/CBN SPC.

The following sections present guidelines and procedures for employing GPS technology and establishing a GPS survey control network.

25-2.0 GUIDELINES AND PROCEDURES

<u>25-2.01 Horizontal Control</u>

Where practical, INDOT project surveys should be based on North American Horizontal Datum 1983 (NAD 83) with adjusted FBN/CBN SPC. The SPC should only be used for reference purposes or to re-establish control. The topography data should not be collected under SPC.

The SPC should be transformed to a local coordinate system upon completing the control network. Such a capability is available in most GPS software packages. To achieve optimal results, create a local Transverse Mercator projection for a north-south strip and a local Lambert Conformal Conic projection for an east-west strip or an Oblique Mercator projection for an angled strip. Establish the local coordinate system on a value that is obviously not an SPC (e.g., 10 000, 10 000). For distances within the conventional measurement range (e.g., <1700 m), differences between local grid and actual ground measurements should be negligible thus minimizing the need for SPC grid to ground conversions.

Both the FBN/CBN SPC network coordinates based on NAD 83 horizontal datum, and the local grid coordinates, should be submitted for all centerline control points and section corners. The SPC data should not be used for general topography. Until the adjusted FBN/CBN coordinates are published, constrain the final GPS adjustments to only one NAD 83 horizontal control.

25-2.02 Vertical Control

The Department prefers that the North American Vertical Datum 1988 (NAVD 88) be used for the vertical control of INDOT projects that are based on National Geodetic Survey (NGS) bench marks. Many of the existing GPS software packages require that NAVD 88 datum be used for elevation calculations. It should be noted that the National Geodetic Survey contains all of the previous records of the USC&GS database which should not be confused with the U.S. Geological Survey (USGS). The accuracy of other datum (e.g., USGS, INDOT) is not as dependable because some of the recorded bench marks were based on estimates or trigonometric observations.

All NGS data for the State of Indiana is available on computer CD. Copies may be purchased from the National Geodetic Survey. Optionally, the NGS data may be obtained through the Internet under "Products and Services" at address http://www.ngs.noaa.gov. The data may be extracted by a PID, a station name or an area that is defined by latitude and longitude.

To maintain vertical control, at least three reliable bench marks should be established. These bench marks should be spaced evenly within the network. Only one bench mark should be fixed at a time as the orthometric height is constrained during final GPS adjustment. Compare the difference between the calculated and the published elevations before constraining to other orthometric bench mark elevations.

25-2.03 Research

An excellent source for obtaining horizontal and vertical controls is the NGS geodetic control diagrams. These diagrams illustrate the position of each horizontal monument, including the lines of observation, and the level circuit between each vertical bench mark. Unfortunately, geodetic control diagrams are no longer published by NGS, and their availability is limited. Additionally, computer mapping software is available that will process NGS control data and produce graphical displays. The USGS quadrangle map base could be digitized perhaps as early as 1998. Until then, the standard USGS quadrangle maps should identify a majority of the horizontal and vertical controls that may be required for the project.

During the research effort, the name of a particular monument should be identified so that its location description and its published data may be obtained. The monument's latitude and longitude should be recorded for use in plotting GPS obstructions during schedule planning. Only one NGS horizontal control is required to tie a project to the SPC system; however, one large geometrically solid triangle may be necessary if the control's locations is far from the project (e.g., up to a 20-km radius for static observations).

The GPS network should incorporate as many existing monuments as practical. Existing centerline control and section corner monuments should be researched and located during the survey. Road plans and field books may be obtained from the Design Division's Records Unit. Information pertaining to section corners may be obtained from the County Surveyor's Office. Other useful information may be acquired by researching surrounding property deeds and by interviewing local surveyors. It should be noted that property owners must be given advanced notice (i.e., Notice of Survey) before accessing monuments or section corners on private property. Chapter Twenty-two presents additional information regarding preliminary research and survey notices.

25-2.04 Reconnaissance

Preliminary research will identify most of the control points within the survey limits of the project, usually by a general description of the monument. However, a field reconnaissance should be employed to physically locate these monuments and to find or set additional project controls. Such an operation may require that the centerline location be calculated from existing points so that additional centerline control may be staked out in order to have a better idea of where to look for a known monument.

If a monument is a potential candidate for inclusion in the GPS network, then satellite vehicle (SV) obstructions (e.g., trees, buildings, power lines) should be plotted, as illustrated in Figure 25-2A, GPS Station SV's Obstruction Chart, and logged in the computer. A schedule of observation times then could be computed. Reference Drawings should be made on the back of the obstruction chart. See Figure 25-2B, Reference Drawing. These drawings should be made for each GPS monument that is either found or set.

Because there may be an unforeseen delay in returning to the job site, each monument should be marked and referenced. Section corners, either found or apparent, must be referenced and recorded. Figure 26-1C illustrates the Department's format for a section corner reference card. Once the FBN/CBN system is completed, adjusted, published and used in the network, the SPC should be placed on all reference drawings.

25-2.05 Network Design

As practical, at least one NGS horizontal control monument and three NGS vertical control monuments should be incorporated in the control network. Additional random monuments may need to be set to create a geometrically strong network.

Two pairs of intervisible points, one pair located at each end of the project, are required so that beginning and ending bearings may be used to close the conventional traverse angles. For projects greater than 5 km, an additional pair, located near the center of the project, should be considered so that two shorter traverses can be constructed. This should minimize errors that are normally associated with closing very long traverses.

The control networks should be collected using either static or fast static observations. Either kinematic or real-time kinematic (i.e., RTK) observations may be used for other singular control points. Where a random point must be set for the purpose of general control or strength-of-figure, do not set the monument near the centerline or a property line as the random point may then be mistaken for such monumentation. It is also desirable to keep all control points within the project's right-of-way or at least on public property. The spacing of the final centerline control monuments and the bench marks should not exceed 300 m.

25-2.06 Scheduling

Prior to developing a schedule, determine the day upon which the field observations will be conducted. If GPS observations have not been conducted recently, then a new ephemeris should be collected because satellite orbits are altered frequently. An old ephemeris is not reliable. After plotting the obstructions and computing the observation times for all points in the GPS control network, then a schedule should be made to accommodate those points having limited visibility. To avoid rescheduling, the ephemeris should be less than one week old. A new ephemeris should be collected the day before conducting the scheduled observations, and the schedules should be checked for alterations.

The best geometric control network is one that is composed of triangles similar to a steel bridge structure. A single observation session produces a number of measured baselines that is equal to the number of receivers used minus one. Therefore, the optimal number of receivers to use in network design is four. However, with considerably more forethought and difficulty, the task may be conducted with two or three receivers.

Preferably, the first observation setup should be on the fixed horizontal control point. If four receivers are being used, three receivers should be set up in a triangular configuration that will measures the three desired baselines. The fourth receiver (i.e., the dummy) should be set at a point on the next desired triangle. For each subsequent observation session, the farthest receiver is moved to the next point in the network. During each session, it is ideal to obtain a measured baseline for each leg of the triangle. This will produce redundancy for better least squares adjustment results.

For fast static observations that are collecting L1 and L2 frequencies with P-code, the required time for 15-second epochs is as follows:

1. 20 minutes or more for four observable satellite vehicles,
2. 15-20 minutes for five satellite vehicles, and
3. 8-10 minutes for six or more satellite vehicles.

A typical schedule may incorporate 15-minute observation periods with an average of 25-minute relocation times similar to the example presented in Figure 25-2C, Fast Kinematic GPS Observation Sheet. Each session's receiver must collect data simultaneously from the same satellites during the same minimum time period. Radio communication between each receiver's operator is desired so that, if a problem occurs, an allowance can be made to immediately avoid an erroneous observation session.

25-2.07 Equipment Preparation

Charge all batteries before conducting the field observations. Check and adjust tribrachs for both level and optical plummet. Tighten the tripods to eliminate wobble. If a prism pole is used in any Kinematic observation, be sure to adjust the spirit bubble so that an accurate location can be obtained. Set the correct parameters for the type of observations being made on all receivers (e.g., type of observation, type of antenna, type of antenna height measurement, the epoch time length, the local time zone). The file name is usually the concatenation of a unique four-character name of the observed monument, the Julian day and the session number (e.g., BASE1941). Ensure that a sufficient number of observation forms have been prepared for all of the planned sessions.

25-2.08 Field Observations

A failure to adhere to the planned observation schedule will produce an erroneous session. If radio contact cannot be maintained between receiver operators, then adhering to the planned schedule becomes extremely important. If a receiver battery needs to be changed, it should be changed during a scheduled move because the data collection period must be both synchronized and continuous. Some receivers have the capability of maintaining power during a battery change. Points that do not necessarily have to be a part of the control network may be collected by employing GPS kinematic observations. The observation forms presented in Figure 25-2D, GPS Field Data Sheet, and Figure 25-2E, Special Situations and Station Description Sheet, should incorporate the following information.

1. project name;

2. project location;

3. USGS quadrangle map;

4. observation date;

5. type of receiver and antenna including serial numbers;

6. observer's name;

7. station name and identification;

8. each session's start and stop observation times;

9. antenna heights and how they were measured (e.g., true vertical, slope to ground plane); and

10. any conflicting occurrences including the time span (e.g., a battery change, a large truck that stopped and obscured the target for more than one minute).

Review the observation forms for any potential problems that may be corrected by another session in the field.

<u>25-2.09 Downloading Receivers</u>

Review the data collection observation forms for any changes that may be required in the file information. Download the data from each receiver and check file names, point names, antenna heights and fixed control information.

<u>25-2.10 Data Processing</u>

One control point should be fixed both horizontally and vertically (i.e., ellipsoidal height) for baseline processing. To process baseline data, specify the generation of all baselines and select the set of independently measured baselines. Review the ratios, reference values and solution types of the detailed summary to determine measurement quality. The results then should be saved. Visually check the network map for any gross errors. Determine the closure on both the network perimeter and any additional circuits and check the vertical bench marks. Save and print the results. Baseline closures should be better than 1 in 100 000. If an observation session is erroneous, then recompute the observation times under a different time frame and repeat the observation session. Once quality data has been collected for each baseline, then begin the least square's adjustment and constrain to only one fixed horizontal control monument. The results should be compared with other known quantities so that particularly erroneous points may be isolated. Upon completing the fully constrained adjustment and the time frame, repeat the observation session. Quality data should be changed to Indiana State Plane Coordinates (i.e., either east or west). Save and print the results for reference purposes. A local plane coordinate system then should be created. This could be either a Transverse Mercator projection for a north-south route, a Lambert Conformal Conic projection for an east-west route, or an Oblique Mercator projection for an angled route. Typically, the planes will be so close to the ground that the resulting difference between grid and ground distances will be quite negligible. The result then should be saved and printed as it will become the control for all ground work. Verify the results during the bench level circuits and the conventional traverse which will need to be run in order to set the centerline control and the fly stations for topography.

25-2.11 Conventional Traverse

After the network is finalized, then the conventional traverse for local control and centerline stakeout may begin at the two intervisible GPS control points and then continued to the next two intervisible GPS control points. Centerline control points should not be spaced more than 300 m. Run bench level circuits between either bench marks or GPS control points. Temporary bench marks should be set, where practical, within the right-of-way and should not be more than 300 m apart.

25-2.12 Submittals

So that other projects that have common control monumentation may benefit from previously collected data, the Department requires the following information to be submitted.

1. raw .dat files that have been downloaded from receivers,
2. copies of the GPS station satellite vehicle obstruction charts,
3. GPS field data sheets,
4. a network diagram illustrating the measured baselines, and
5. adjusted SPC and Local Projection coordinates with projection definition.

Preferably, the network diagram should be presented on a copy of the USGS quadrangle map. By maintaining a database of raw project data, multiple networks may be tied and processed together.

A standard program function for transferring data is to make a backup copy of all project files. For Trimble receiver software, this function is located under the menu selection; GPSurvey, Desktop, Project, Backup. If the GPS data has been collected using another brand of receiver software, the data transfer may require the use of the RINEX file format. The Department requires that all data be backed up in both formats (i.e., standard and RINEX) before it is deleted.

In addition to the electronic media, a hard copy of the results should be submitted. This should include the following:

1. Processed Baseline Summary. A detailed summary of the processed baselines that presents the ratios, reference values, solution types and the quality of the measurements shall be included.

2. Closure Log. Include a closure log that presents the various combinations of network loops and the validity checks of the measurements. This should include the outer perimeter as well as inner loops and bench mark loops. All combinations of loops should be investigated to locate the weakest link in the network. The precision and the delta misclosures for the Northing, Easting and the elevation should be noted for each loop.

3. Summary of Covariances. Include a summary of covariances that presents the precision on each baseline resulting from the redundancy of measurements.

4. Map Projection Transformation Sheet: SPC. A map projection transformation sheet that illustrates the transformation parameters from the geodetic coordinates (i.e., latitude, longitude) to map coordinates (i.e., Indiana State Plane Coordinates east or west) for each point should be included. This should include the coordinates, the scale and the convergence angle.

5. Map Projection Transformation Sheet: Local Coordinates. Include a map projection transformation sheet that presents the transformation parameters from the geodetic coordinates to map coordinates for each point in the local coordinate grid. This should include the type of projection in addition to the coordinates, the scale and the convergence angle.

6. Final Coordinate Adjustment Summary. The final coordinate adjustment summary for each point should also be included. This should indicate the points that were fixed horizontally and/or vertically. The summary also should indicate whether the elliptical or the orthometric height was held fixed (preferably, orthometric height held fixed).

7. Long Inverse Printout. Include printouts of several long inverses (i.e., full information inverses) between control points and indicate the inverse information for the local grid and the geodetic ground distances. This should be conducted for a short, a long and an

average distance. In comparing this information, the locally defined grid distances should be very close to the ground distances (i.e., within 10 mm).

This information should be easily compiled and printed from the software through a standard report selection. If for some reason the software does not have this capability, then contact the Design Division's Location Surveys Unit for alternatives.